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THE INFLUENCE OF SOME FACTORS ON CUTTING FORCE AND SURFACE ROUGHNESS OF WOOD AFTER SANDING

Ľubomír JAVOREK
Technical University in Zvolen
T. G. Masaryka 24, 960 53 Zvolen, Slovak rep.
++421 45 5206 546, Fax: ++421 45 5320015, E-mail: lubomir.javorek@tuzvo.sk

Jozef KÚDELA
Technical University in Zvolen
T. G. Masaryka 24, 960 53 Zvolen, Slovak rep.
++421 45 5206 334 Fax: ++421 45 5320015, E-mail: jozef.kudela@tuzvo.sk

Ján SVOREŇ
Technical University in Zvolen
T. G. Masaryka 24, 960 53 Zvolen, Slovak rep.
++421 45 5206 548, Fax: ++421 45 5320015, E-mail: jan.svoren@tuzvo.sk

Mária KRAJČOVIČOVÁ
Technical University in Zvolen
T. G. Masaryka 24, 960 53 Zvolen, Slovak rep.
++421 45 5206 575, Fax: ++421 45 5320015, E-mail: maria.krajcovicova@tuzvo.sk

Abstract

This contribution presents results of an experimental research on sanding. With a sample of oak being the experimental material, sanding was carried out on radial, tangential and transversal surface of the piece. The impact force was changed on three levels (21 N, 41 N and 58.5 N), the grain size of sanding belt in four levels (40, 60, 80, 100). The constant parameters were: cutting speed 200 $m \cdot min^{-1}$, moisture content of the sample 12%. The cutting force and surface roughness were measured and cutting force was recaltutated to 1 mm of wideness of sanding belt. The cutting force was: within 0.80 till 1.0 $N \cdot mm^{-1}$ for oak, impact force 21 N, for all surfaces and for all grain size; within 0.47 till 0.54 $N \cdot mm^{-1}$ for oak, impact force 41 N, for all surfaces and for all grain size; within 0.23 till 0.26 $N \cdot mm^{-1}$ for oak, impact force 58.5 N, for all surfaces and for all grain size. Surface roughness alternated within limits 4.42 μm – 14.43 μm depending up grain size, impact force and character of sanded surface. The minimum valids for grain size 100, transversal surface and impact force 21 N; maximum valids for grain size 40, tangential surface and impact force 41 N. Surface roughness was measured in perpendicular direction to cutting direction.

Key words: *sanding of wood; impact force; cutting force; surface roughness.*

INTRODUCTION

Sanding of wood is a very frequent object of reaserch in the word. The reason is that sanding is usually the last operation of surface modification before lackering or painting and the technology may improve surface quality and ensure dimensional accuracy of worpiece. The quality of sanding surface directly determinates the final effect: as for as both the potential customer's interest (i.e. the succes on the market) and the resistance against weather conditions are concerned.

Sanding can be charakterized as machining with a lot of cutting wedges with non-defined geometry. This geometry is coined by grains of the abrasive material, joined together by means of a binding material.

In generaly, the rake angle of grains is crushingly negative, the chip is modified under a big angle φ_1 in the zone of machining and the temperature in this area may rise, by **Banský, Naščák, Wieloch** (1999), up to 230°C; They tested the influence of temperature and grain size (P80 and P120) on the surface roughness of the chipboard and MDF board. The influence of temperature on the surface roughness was the most intensive for grain size P80.

The significance of sanding technology arises together with the evolution and production more and more productive grinders and the original purpose sanding machine for finishing is extended for roughness too. In this case, sanding may compete with other metods of machining.

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The main characteristics of sanding according to **Driensky** (1986) are:

- irregular stylus fillet,
- irregular geometrical shape,
- high hardness and termical resistance,
- high cutting speed (from 30 mps until 120 mps,
- short-lasting contact with the machined workpiece (cca 0,0001 s),
- small size of grains (from 0,003 mm to 3 mm),
- very small cross section of the chip (from 10^{-3} mm^2 until 10^{-5} mm^2),
- wearing of grains during the sanding process, i.e. degresion of the cutting property.

A model of the chip removing including a definition of the basic geometry according to **Maslov** (1979) is displayed in Fig. 1.

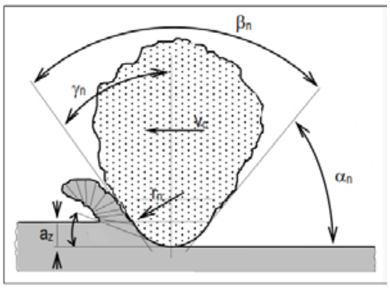


Fig. 1.
Model of the chip removing (Maslov 1979)

α_n – clereance angle, β_n – wedge angle, γ_n – rake angle, r_n – radius of cutting wedge, ϕ – angle of the primary plastic deformation, a_z – depth of the grain penetration into the material, v_c – cutting speed

Influence of the grain size on the surface roughness was in focus of **Bahchevandziev a Manev** (1999) who used a chip board covered with veneer from beech and pine as their experimental material. The granularity of abrasive papers were P100 and P150, respectively P120, P150, P180 and sanding was carried out in parallel and vertically compared with fibres. The experiment confirmed significant influence of last sanding direction to final surface roughness.

Očkajova and Siklienka (2000) solved influence of the wood species, orientation of wood’s fibres, and sort of the grinding material on the volume of wood removed per minuta. They stated a correlation between removed material and species of wood, grain size, as well as fibre of wood orientation.

The research objective of **Ayrilmis, Candan, Akbulut, Balkiz** (2010) was to investigate the effects of sanding on the surface properties of the medium density fiberboard (MDF) panels made from Rhododendron ponticum L. wood. The MDF panels were sanded with different sizes of the sand paper grit: P60; P60+P80; or P60+P80+P120 grit. Surface absorption and surface roughness of the MDF panels were determined on the basis of the EN 382-1 standard and ISO 4287 by using a fine stylus profi lometer. The MDF surface sanded with a 60-grit size had a lower contact angle and more wettable surface compared to the surfaces sanded with P60+P80+P120 grit sizes.

The paper by **Fotin, Cismaru, Marthy, Brenci, Coseranu** (2011) presents the results of experimental research studies dealing with the power consumption during the process of sanding birch wood with grain sizes of P60, P80, P100 and P120 with regard to three processing directions (parallel, perpendicular and at 45º angle to the wood structure orientation). The industrial experiments were performed at NIKMOB Company, on the wide belt sander machine using an electronic device and a data acquisition logger in order to record the power consumption. The factorial experiment with two variables (feed speed and cutting depth) was used.

Fotin et al. (2013) presented results of the experimental research on the quality of birch wood surfaces after sanding them with P60, P80, P100 and P120 grains sizes, analyzing the roughness parameters of the sanded surfaces in each phase. The birch wood specimens were sanded parallelly, perpendicularly and with a 45-degrees inclination towards the wood fibres.

The paper by **Jaić, Palija, Dobić** (2010) presents a research of the influence of the system of surface finishing on the most significant decorative properties of the dried film: color and gloss. The samples were made from two species of Paulownia (Paulownia elongata and Paulownia fortunei).

In the study by **Richter, Feist, Knaebe** (1995), analysis results of a relationship between the morphological structure of the outside wood layer (surface roughness), and the performance of coatings are given. The surface roughness of five roughness categories (processed by planing, sanding, and bandsawing) on three wood substrates (vertical- and flat-grained western redcedar and flat-grained southern yellow pine) was determined by stylus tracer measurements.

The aim of the reasearch of **Tian** and **Li** (2014) was to explore the correlation between the sanding efficiency and the surface quality. As testing material were used Manchurian ash, Birch and MDF board, technological conditions were in longitudinal and transverse direction to wood fibres and grain sizes of paper P60 and P100 as influencing factors, analyzed their influence on the sanding efficiency and the surface quality. Results indicated that the highest sanding efficiency was obtained by MDF when sanded with the P60 grain size abrasive belt, Manchurian ash acquired the lowest sanding efficiency when sanded with the P100 grain size abrasive belt in longitudinal direction. Moreover, the lowest Ra was yielded by Manchurian ash when sanded with the P100 grain size abrasive belt in transverse direction; MDF gained the highest Ra when sanded with the P60 grain size abrasive belt. It also could be noted that there was not a visible correlation between sanding efficiency and surface quality in all cases of the study, but the belt should be replaced when the material removal rate decreased to a certain level in order to acquire better product quality and economic efficiency.

Sanding of non- and hydro-thermally treated oak was in the focus of experiments by **Wilkowski et al.** (2011). They used an equipment with a loaf grinding bit, and a CNC machine with vaccum clamping system for fixing of worpiece. For wood machining, following parameters were used: granulation of abrasive paper P40, dimensions of grinding bit 30mm/60mm, depth of cut 1mm, feed speed 1mpm and rotational spindle speed 2000rpm.

The experimental results from sanding different wood species (conifers, broadleaves) with known internal anatomical characteristics were used in the experiment by **Magoss** (2013): 4 different grain sizes were applied in the range of P80 and P240 were presented in diagrams showing the basic relationships between the surface roughness parameters and grain diameters (4 different grain sizes), the roughness parameters and structure number for all wood species, and internal relationships between roughness parameters.

According to **Gurau** (2013) and **Gurau** (2014) sanded wood surface have different irregularities caused by machining and wood anatomy; the wood anatomy was excluded from the roughness profiles using a method based on the Abbot-curve. Latewood was smoother than earlywood with the greatest ratio in oak, followed by spruce and beech. The author used paper with P180 and P120 grain sizes, diferent for various samples.

The effects of wood dust on humen health were analysed by **Darii and Badescu** (2011). Spruce, beech and MDF were used as experimental materials, cutting speed was constant (18 mps) and granulity of used papers was P40, P60, P80, P100 P150. From all the parameters the feed speed, pressure, moisture content and density of the material have a considerable influence on the resulted volume of chips.

The influence of the impact force (21 N, 41 N and 58.5N), feed speed (50mpm, 150 mpm, 200 mpm), sample of wood (spruce, oak, beech), type of the surface (radial, tangential, transversal), and size of the grids (P40, P60, P80, P100) on the cutting force and surface roughness were in focus of **Šuniar** and **Javorek** (2013) research. In this research, 648 pieces for every wood species were used, i.e. 1944 pieces altogether. This paper presents a reduced overview of the research – for oak, cutting speed 200 mpm only.

OBJECTIVE

The main objective of the presented research was to evaluate cutting force and surface roughness as functions of the cutting speed, impact force, species of wood and sanding direction in the face of wood's fibres orientation.

MATERIAL, METHOD, EQUIPMENT

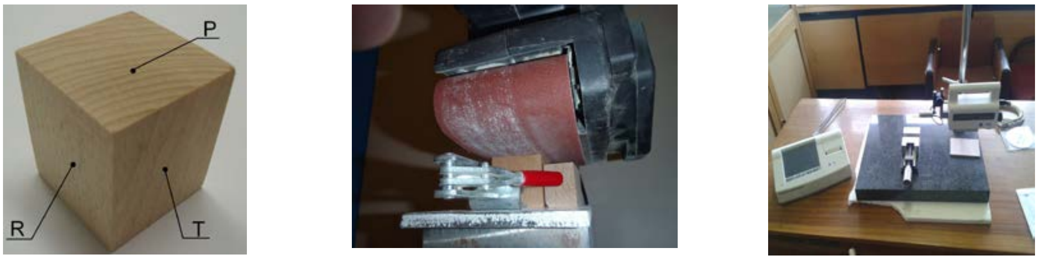
English oak (*Quercus robur* L.) was used as experimental material. The samples were prepared as a box of 60 mm x 60 mm x 60 mm so, that its sides functioned as radial, tangential and transversal surfaces. Oak is one of the most important hard wood species in Slovakia (preceded by beech and followed by maple); at present it covers app. 10.7 % of the Slovak forest area. **Klement et al** (2011) declares physical properties of the raw material with moisture content 12%. Some of the properties are shown in the Table 1.

Table 1

Physical properties of the experimental material

<table>
<tr><td colspan="2">Density [kg.m^{-3}]</td><td colspan="2">Moisture content of green wood [%]</td><td rowspan="2">Fibre-saturation point humidity [%]</td></tr>
<tr><td>in absolute dry status ρ_0</td><td>reduced in fresh status $\rho_{r\check{c}}$</td><td>sapwood</td><td>adult wood</td></tr>
<tr><td>390 / 650 / 930</td><td>550</td><td>70 - 100</td><td>60 - 90</td><td>32 - 35</td></tr>
<tr><td rowspan="3"></td><td colspan="3">Linear shrinkage in direction</td><td rowspan="2">Volumetric shrinkage</td></tr>
<tr><td>longitudinal</td><td>radial</td><td>tangential</td></tr>
<tr><td>0.4</td><td>4.0</td><td>7.8</td><td>12.2</td></tr>
</table>

The goal of the experiment was to state the influence of grain size (P40, P60, P80, P100), impact force, (*21 N, 41 N, 58.5N)*, cutting speed (200 mpm), and feed direction toward to wood's fibres (parallel or perpendicular) on the cutting force and surface roughness. The surfaces of the experimental samples were defined as tangential (T), radial (R) and transversal (P).



a ***b*** ***c***

Fig. 2.

a - Definition of machined surfaces; b - Detail of sanding; c - Surface roughness measuring

Piezoelectric measuring sytem (Fig. 3.) made by Kistler (Kistler Instrumente AG, Switzerland) was used for measuring the cutting force. The system was also used for checking the impact force. The basic parts of the system were:

1. Dynamometer 9275B (parameter see Table 2).
2. Multichanel Charge Amplifier 5070A.
3. A/D Converter – DAQ System 5657A1.
4. PC + softver DynoWare.

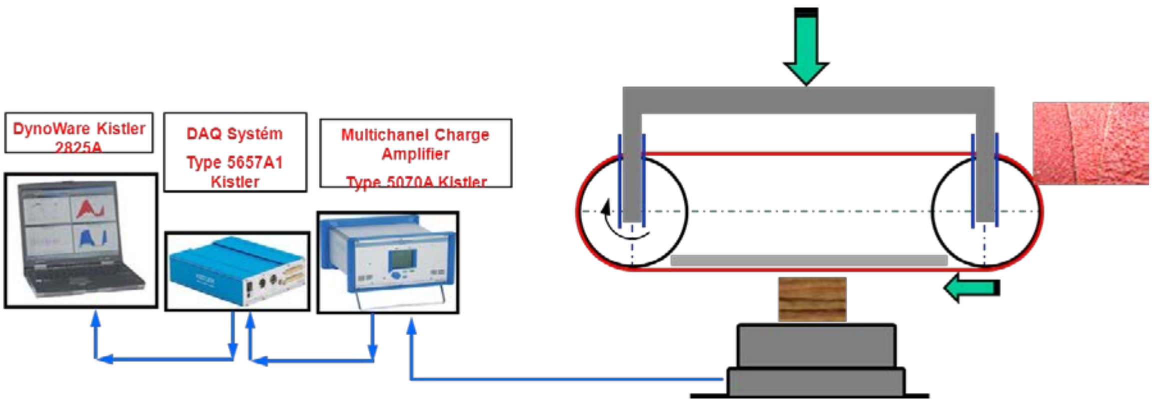


Fig. 3.

Scheme of the measuring chain

Table 2

Dynamometer typ 9257A – chosen technical parameters

Range force application	F_x, F_y, F_z	kN	– 5 ... 5
Overload	F_x, F_y, F_z	kN	–7,5 / 7,5
F_x and F_y ≤0,5 F_z	F_z	kN	–7,5 / 15
Response threshold		N	< 0,01
Sensitivity	F_x, F_y	pC/N	≈ –7,5
	F_z	pC/N	≈ –3,7
Linearity (all ranges)		% FSO	≤ ±1
Rigidity	c_x, c_y	kN/μm	>1
	c_z	kN/μm	>2
Natural frequency	f_n (x, y, z)	kHz	≈3,5
Natural frequency (mounted on flanges)	f_n (x, y)	kHz	≈2,3
	f_n (z)	kHz	≈3,5
Operating temperature range		°C	0 …70
Temperature coefficient of sensitivity		% / °C	– 0,02
Capacitance (of channel)		pF	220
Ground insulation		Ω	$>10^8$

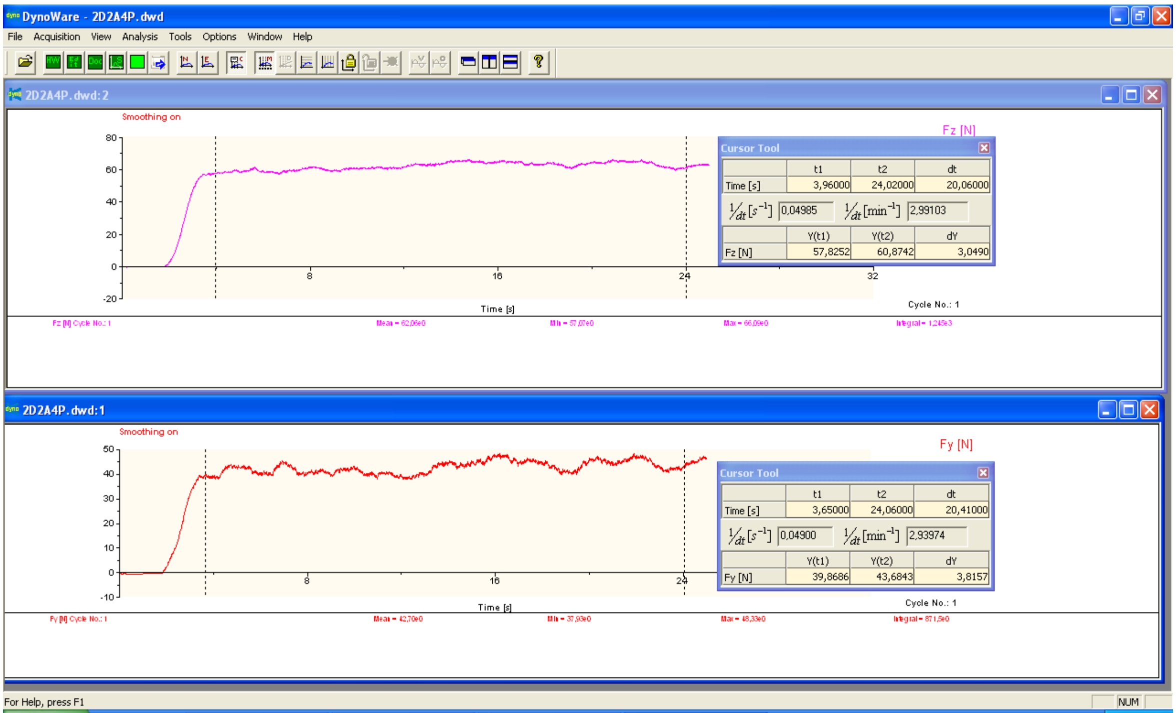


Fig. 4.
The records of the impact force (Fz) and cutting force (Fy)

RESULTS AND DISCUSSION

A fullfactorial experiment was carried out, i.e. for all variations of all independed variables. Involved results valid for one-factorial analyse. Cutting force was recalculated to 1mm-wide sanded surface, therefore quoted unit of force is $N \cdot mm^{-1}$. The surface roughness was measured in the direction of cutting speed and in the direction perpendicular to cutting speed.

Fig. 5 displays the influence of impact force (A=58.5N), grain size of belts and type of the surface (R, T, P) on the cutting force. The values of forces for radial and tangential surfaces are very similar – only for grain size 40, there is a diference of $0.12 N \cdot mm^{-1}$. It looks like very small, but for a 300 mm-wide board, for instance, it is 36 N, and for a 1000 mm-wide bioboard it is 120N. Therefore it is important to bear in mind this fact when processing wider plates.

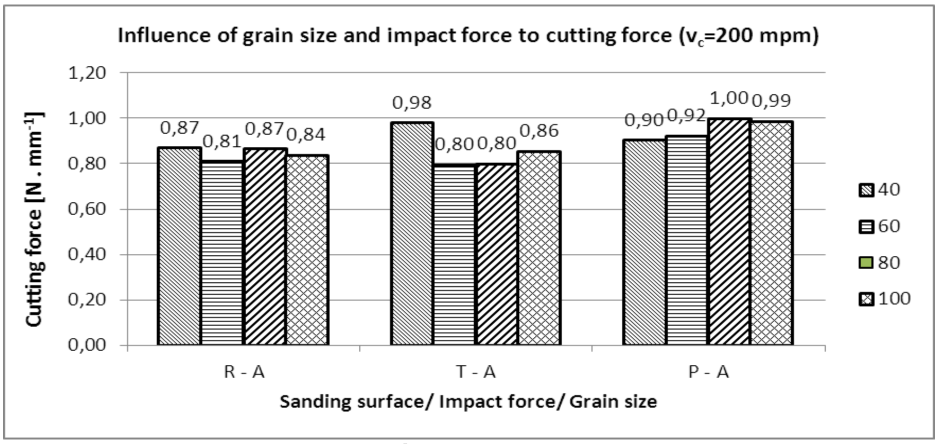


Fig. 5.
Influence of grain size and impact force A on the cutting force (oak, v_c = 200 mpm)

Values in the graph in Fig. 6 display analogical independed variables as the graph in Fig. 5. Nevertheless, the value of impact force was B=41 N, i.e 1.4-time lower. The graphs look similar but the value of cutting force was lower by 40% till 50%.

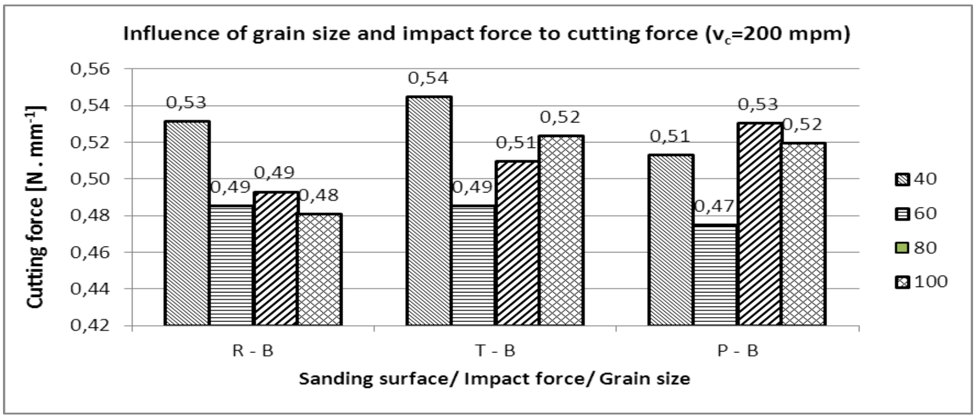


Fig. 6.
Influence of grain size and impact force B on the cutting force (oak, v_c = 200 mpm)

The graph in Fig. 7 illustrates results received during sanding with impact force C=21 N, i.e. 2.7-times smaller than force A and 2-times smaller than force B. This is evident in the decrease of the cutting force. However, if we compare radial, tangential and transversal surfaces, the cutting force increases practicaly in every case.

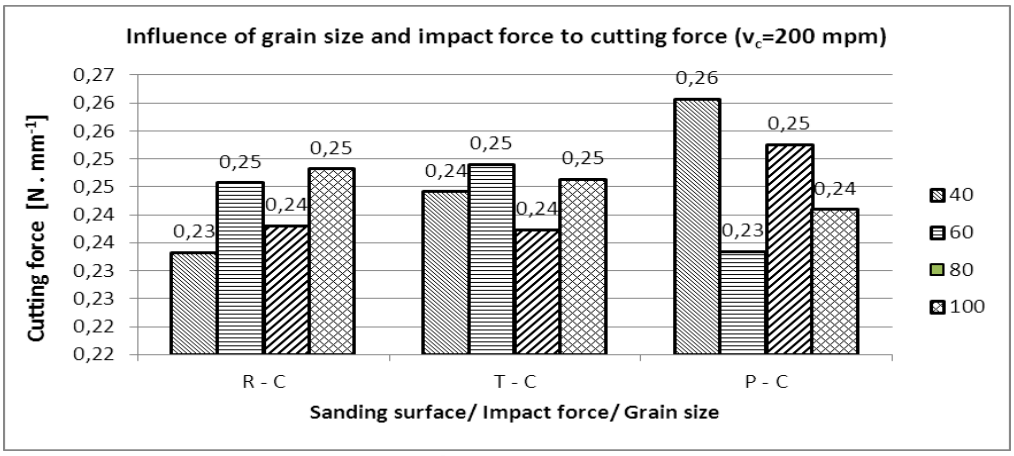


Fig. 7.
Influence of grain size and impact force C on the cutting force (oak, v_c = 200 mpm)

The evaluation of surface roughness is in follows part; as arithmetic average of absolute values, i.e. parameter Ra. For measuring the surface roughness, Surfcom 130A was used; contact measuring system with radius of stylus tip 2±0.5μm, cut-off was 0.8mm, evaluated length 30mm. The influence of the measure direction was very significant (see records in Fig. 8. resp. in Fig. 9.). Values for perpendicular direction were cca 2.5-times higher. (This paper only presents results from perpendicular direction measuring).

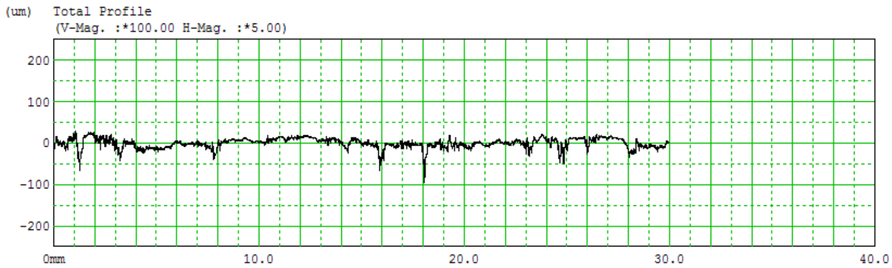


Fig. 8. Surface roughness in direction to sanding direction

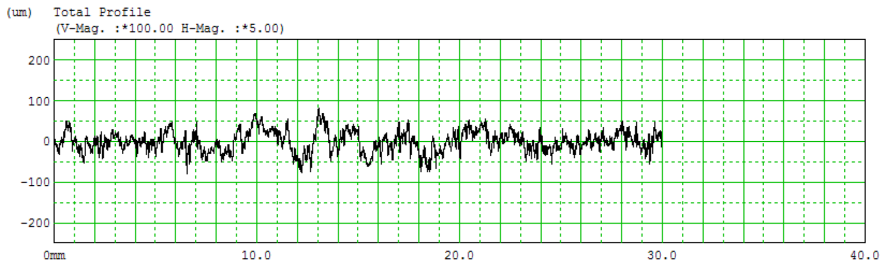


Fig. 9.
Surface roughness in perpendicular direction to sanding direction

The graph in Fig.10. presents the average values of surface roughnes as dependent on impact force, type of surface and grain size of oak.

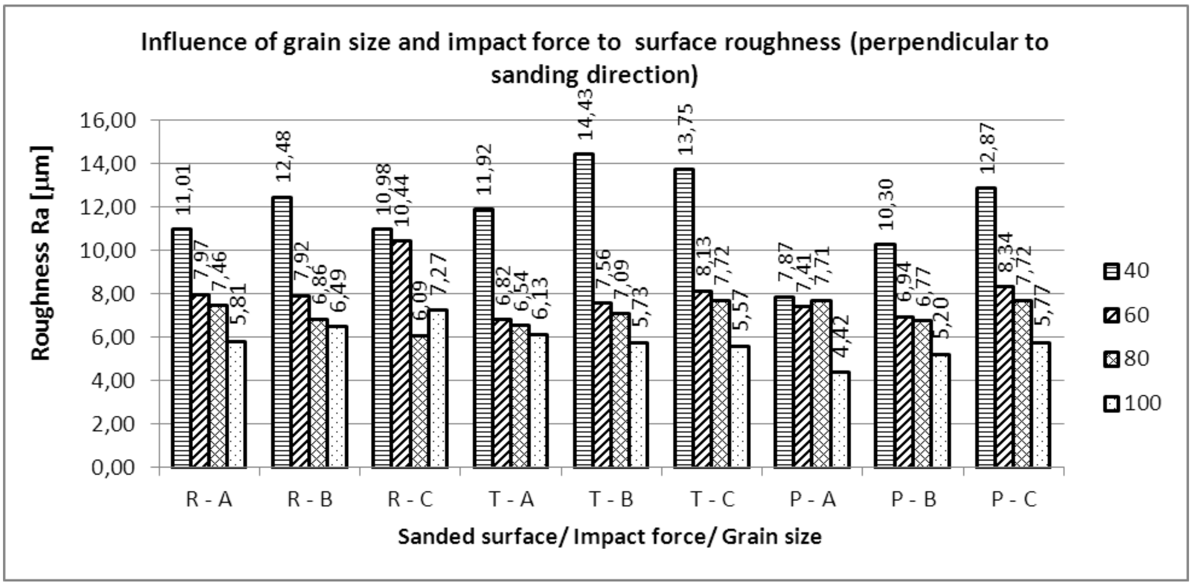


Fig. 10.
Influence of grain size, impact force and sanded surface on the surface roughness in direction perpendicular to cutting direction (oak, v_c = 200 mpm)

From this graph, a very considerable influence of grain size on the value of roughness is evident. It was true of the whole research. For example, for radial surface applies that the change granularity from 1P00 to P40 surface roughness will change (increase) in 89.5% (for force A), in 92.3% (for force B), in 51% (for force C). The average value is nearly 77.2%.

For tangential surface it is (the change granularity from P100 to P40) roughness will increase in 94.4% (for force A), in 151% (for force B), in 146% (for force C). The average value is practically 130.5%.

For transversal surface for the same granularity (P100 or P40) roughness will increase in 78% (for force A), in 98% (for force B), in 123% (for force C). The average value is almost 100%.

CONCLUSIONS

The experiment confirmed the dependency of the cutting force on grain size, impact force and fibres orientation compared with direct of cutting velocity, including the type of the sanded surface (radial, tangential, transversal). These differences of force were not very considerable.

Surface roughness very significantly depends on grain size and impact force. Surface roughness has effect on the speed of liquid interpenetration to wood.

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